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METHOD AND APPARATUS FOR ADAPTING A TRANSMISSION DATA RATE OR A TRANSMISSION POWER TO THE TRANSMISSION QUALITY OF A TRANSMISSION CHANNEL

The invention is directed to a method for adapting a transmission data rate or transmission power to the transmission quality of a transmission channel.

The need for digital transmission systems has exponentially risen in recent decades. Digital transmission systems are generally classified into the function units shown in Fig. 1. A message source 1 generates information that a transmitter transmits to a receiver via a transmission channel 4. The properties of the information to be transmitted are dependent on the message source. Messages to be transmitted can, for example, be an audio signal or a video signal. Analog transmission systems thereby transmit analog signals that were generated by analog message sources directly via the transmission channel upon employment of traditional analog modulation methods. Such modulation methods are, for example, amplitude modulation, frequency modulation or phase modulation. In digital transmission systems, the information to be transmitted is converted into a sequence of binary numbers. In order to be able to utilize the capacity of the channel optimally well, the message to be transmitted should be represented with as few binary numbers as necessary. To this end, a source encoder is employed that has the job of converting the messages to be transmitted into sequences of signal values and encoding them, so that the channel can transmit them. The source encoder thereby attempts to convert the messages to be transmitted into binary numerals as efficiently as possible.

The sequence of binary numbers generated by the source encoder is transmitted by the channel to the receiver. Such an actual channel can, for example, be composed of a line connection, of a coaxial cable, of a light waveguide (LWL), of a radio connection, a satellite channel or a combination of these transmission media. Such channels cannot directly transmit the sequence of binary numbers from the transmitter. To that end, the sequence of digital information must be converted into signal values that correspond to the properties of the channel. Such a device is called a digital modulator. Such a modulator is part of the channel encoder 3, which

additionally comprises a discrete channel encoder in order to provide the information to be transmitted with an error protection adapted to the channel.

It is not assumed of the transmission channel 4 that it works error-free; rather, it is assumed that a noise source 5 will modify the transmitted signals during the transmission with a specific probability.

Such disturbances can, for example, be a cross-talk of signals that are transmitted on neighboring channels. The disturbances can likewise be caused by thermal noise that is generated in the electronic circuit such as, for example, amplifiers and filters that are employed in the transmitter and in the receiver. Given line connections, disturbances can additionally be caused by switchings and can be additionally caused by meteorological influences given radio or satellite connections such as, for example, thunderstorms, hail or snow. Such influences modify the transmitted signal and cause errors in the received digital signal sequence.

In order to nonetheless assure a relatively dependable transmission, the channel encoder increases the redundancy of the (binary) sequence to be transmitted. With the assistance of this redundancy added by the transmitter, the receiver is assisted in the decoding of the information-carrying signal sequence. To this end, for example, the channel encoder combines a specific plurality of signals to form blocks and a plurality of check signals (one parity bit in the simplest case) is added. In this way, k information bits are always simultaneously encoded, whereby each k bit sequence has an unambiguous n bit sequence, what is referred to as the code word, allocated to it. The redundancy added in this way can be indicated with the ratio n/k. This likewise corresponds to the channel bandwidth that must be correspondingly increased in order to transmit the information sequence expanded by the added redundancy.

Alternatively, an enhanced dependability against channel disturbances can also be achieved, for example, by an increase in the transmission power. Since the increase in the transmission power, however, is relatively expensive, the dependability is usually achieved given available bandwidth by increasing the required channel bandwidth.

In the transmission of one bit with the data rate R bit/s, the modulator always allocates a signal curve or, respectively, a signal value (referred to below only as signal value) $s_1(t)$ to the binary number 0 and allocates a signal value $s_2(t)$ to the binary number 1. This transmission of each individual bit by the channel encoder is called binary modulation. Alternatively, the modulator can simultaneously transmit k information bits upon employment of $M = 2^k$ different signal values $s_i(t)$ with $i = 1, 2, \ldots M$, whereby each of the 2^k possible k-bit sequences is allocated to a signal value.

At the receiver side of a digital transmission system, the digital demodulator processes the signal value transmitted in the channel (potentially modified) and allocates an individual number to each signal value that represents an estimate of the transmitted data symbol (for example, binary).

After reception of a signal in the receiver, the demodulator must decide which of the M possible signal values was sent. This decision is implemented in a decision unit (slicer), whereby the decision should be made with minimal error probability. This decision unit allocates a reception value (usually edited) to one of the M possible symbol values.

When, for example, a binary modulation is employed, the demodulator must decide when processing each received signal whether the transmitted bit is a matter of a 0 or of a 1. In this case, the demodulator implements a binary decision. Alternatively, the demodulator can also implement a ternary decision, whereby the demodulator decides for "0", "1" or "no decision" dependent on the quality of the received signal.

The decision process of a demodulator can be viewed as quantization, whereby binary and ternary decisions are specific instances of a demodulation that quantizes the Q-level, whereby $Q \geq 2$ applies. In general, digital communication systems employ a high-order modulation, whereby $m = 0, 1 \ldots M-1$ represents the possible transmitted symbols.

When the transmitted information contains no redundancy, the demodulator must decide at every predetermined time interval which of the M-signal values was transmitted. When the transmitted information, in contrast, contains redundancy, then the demodulator reconstructs the original information sequence on

the basis of the code employed by the channel encoder and on the basis of the redundancy of the received signals. Dependent on the demands defined by the applications, the channel encoder generates signal blocks that make it possible for the channel decoder to either only identify where the specific disturbances have occurred (error-recognizing encoding) or to even be able to automatically correct (error-correcting encoding) errors caused by disturbances (up to a specific maximum number per signal block).

One criterion for the dependability with which the messages are transmitted from the transmitter to the receiver is represented by the error rate. The error rate indicates the average probability with which a bit error occurs at the output of the decoder. The bit error rate indicates the plurality of error bits occurring at the receiver divided by the total number of received bits per time unit. The bit error rate (or symbol error rate when the error frequency of symbols is evaluated) is the most important quality criterion of a digital transmission system. In general, the error probability is dependent on the code properties, on the nature of the signal values employed for the transmission of the information via the channel, on the transmission power, on the properties of the channel, i.e. the strength of the noise, the type of noise, etc., and on the demodulation and decoding method. The significance of the bit error rate for digital transmission systems corresponds to the signal-to-noise ration (SNR) of analog transmission systems.

The error rates with which symbols occur at the output of the demodulator or, respectively, with which bits occur at the output of the decoder are dependent on the properties of the transmission medium, i.e. of the transmission channel, on the selected modulation and encoding strategy and on the average power of the transmission signal. For adaptation of a transmission data rate to a transmission channel, the transmission properties of the transmission channel are traditionally determined by communicating a bit or, respectively, symbol sequence that is known to the receiver. The error rate of the channel can be determined on the basis of a rated-actual comparison in the receiver. In this way, the quality of the current data transmission can be identified. What is disadvantageous about this method, however, is that only the measurement of a possible combination of transmission power,

encoding method and modulation method can be measured. So that a separate measurement need not be implemented for every possible data rate or, respectively, transmission power, iterative methods are usually utilized for finding an optimum transmission data rate or, respectively, transmission power.

An object of the invention is to create an improved method or an improved apparatus for adapting the transmission data rate or/and the transmission power to the transmission channel.

This object is achieved for an apparatus with the technical teaching of patent claims 1 and 9 and is achieved for a method with the technical teaching of patent claims 10 and 17.

Advantageous developments of the invention are recited in the subclaims.

Inventively, a transmission data rate or a transmission power is set dependent on the measured signal-to-noise ratio of the transmission channel. The maximally possible data throughput can be determined with the measurement of the transmission quality, particularly of the signal-to-noise ratio, of the transmission channel, and, accordingly, a transmission data rate can be defined or the transmission power can be minimized dependent on the transmission data rate employed.

In this way, the transmission sequence of modulator/transmission channel/demodulator can be measured on line (i.e., during the data transmission) independently of the selected encoding method, and the transmission power or/and the encoding method can be set such dependent on the required data transmission rate that a predetermined bit or, respectively, symbol error rate is guaranteed. The measurement of the signal-to-noise ratio is the prerequisite in order to define an encoding method that can be found for a maximally acceptable error rate of the maximally possible data throughput and in order to define the minimum transmission power such for a defined transmission rate that a maximally acceptable error rate is not exceeded. It is particularly advantageous that a single measurement suffices for finding an encoding method that allows the maximally possible transmission rate with reference to the current transmission channel and the modulation method employed, in contrast whereto every possible combination of transmission power, encoding and modulation method must be traditionally measured. It follows therefrom that a

change in the data rate is possible without interruption ("soft switching") as long as the modulation strategy that is employed is retained.

Additionally, the power of the transmitter can be adapted to the required transmission quality in that the transmission power is raised or, respectively, lowered dependent on a difference between a measured signal-to-noise ratio and a required signal-to-noise ratio. In this way, the transmission power, based on a measurement of the signal-to-noise ratio, can be optimally adapted, i.e. minimized, to the selected transmission method and the existing transmission channel, i.e. lowest possible transmission power given simultaneous assurance of the quality demands and adherence to the required transmission rate. The noise emissions are thus minimized and, at the same time, the transmission capacity of neighboring systems that work on the same frequency band is increased.

Preferred exemplary embodiments of the invention are explained below on the basis of the drawing. Shown are:

Fig. 1 the general structure of a message transmission system;

Fig. 2 the structure of an inventive transmission system for adapting the data rate and the modulation method to the transmission medium on the basis of receiver-side signal-to-noise ratio measurement.

Fig. 3 the structure of an inventive transmission system for adapting the transmission data rate, the modulation method and the transmission power to the transmission medium on the basis of receiver-side signal-to-noise ratio measurement; and

Fig. 4 a diagram for illustrating the "power control" for setting a transmission power dependent on a measure and on an employed transmission quality.

In digital information transmission, information are transmitted between a message source (transmitter) and a receiver via a transmission medium. Such an apparatus that is located between the transmitter and the receiver is generally referred to as channel.

For the transmission, the data to be transmitted are converted into code words that are matched to the transmission properties of the message channel in order to protect the data to be transmitted against among other things, transmission errors.

In the transmission, a character, which is generally referred to as symbol in the signal space or channel symbol, is allocated to a bit sequence with a reversibly unambiguous, functional allocation. This symbol is subsequently mapped onto a signal curve (referred to below as signal value). The functional allocation of a symbol to a bit sequence in the transmitter is called encoding or mapping; the mapping of such a symbol or of a plurality of such symbols onto a signal value is called modulation.

The reversal of this mapping sequence occurs in the receiver. Whereas the demodulation, i.e. the allocation of a reception signal to a symbol, can usually not be implemented error-free due to distortions or superimposed disturbances of the channel, the decoding, i.e. the conversion of a detected symbol into the corresponding bit sequence, does not represent any problems.

Fig. 2 shows the structure of a transmission system that sets a desired data rate after determination of the quality of the quality of the transmission channel. A digital information, particularly a bit sequence 13, is transmitted to a receiver 12 from a transmitter 10 via a transmission channel 11, said receiver 12 outputting the received digital information, particularly the bit sequence 25. The channel encoder 14 of the transmitter 10 contains a digital channel encoder 50, a bit/symbol converter 15 and a modulator 17. The digital channel encoder 50 adds redundancy to the incoming bit stream 13. The encoded bit stream 51 formed in this way is converted into a symbol sequence 16 in the bit/symbol converter 15, this symbol sequence 16 being in turn reversibly unambiguously mapped by a modulator 17 onto a signal curve or, respectively, signal values 18. The signal values 18 are transmitted via the transmission channel 11 to the receiver 12.

The channel decoder 20 of the receiver 12, which converts the received signal values 19 into a digital information 25, contains a demodulator 55, a symbol/bit converter 24 and a digital channel decoder 52 as critical components. In the demodulator, the received signal values 19 are initially edited by an analog and optional digital signal processing unit that, for example, could contain a reception amplifier, an analog-to-digital conversion and a distortion correction means. The

signal values 21 edited in this way are subsequently supplied to a decision unit or, respectively slicer 22 that allocates a symbol 23 to every received signal value 21.

The symbol/bit converter 24 of the channel decoder 20 allocated and encoded, digital information or, respectively, an encoded bit sequence 53 to each detected symbol or, respectively, each detected symbol sequence 23 according to the selected mapping method, the digital information or, respectively, the bit stream 25 being derived therefrom with the assistance of the digital channel decoder 52 according to the selected encoding method.

The decision unit (slicer) 22 is a basic component part of every demodulator. Such a decision unit allocates the symbol or, respectively, the symbols that was most probably sent to the reception value - usually edited. Since the set of input values of the decision unit, due to disturbances or distortions of the transmission channel, usually does not correspond to the "valid" signal values of the transmitter, i.e. the signal values that are allocated to the symbols to be transmitted, the signal-to-noise ratio 28 adjacent to the decision input can be determined from the input signal 21 and the output signal 23 of the decision unit independently of the encoding and mapping algorithm employed. To this end, an inventive receiver comprises a device 27 for measuring the signal-to-noise ratio (SNR) of the information transmitted via the transmission channel 11.

In a possible embodiment of a device for measuring the signal-to-noise ratio, a signal value 60 that the input of the decision unit in the demodulator would have received if the signal curve or, respectively, signal value corresponding to the detected symbol had been transmitted unfalsified is again allocated to every detected symbol in the demodulator at the receiver side. In this way, a hypothetical input signal corresponding to the detected symbol values that contains no signal values with channel distortions or disturbances is formed. This reference signal - as long as the decision unit does not detect any incorrect symbols - thus corresponds to the original signal at the transmitter side. By subtracting this reference signal from the edited receiver signal 21, the noise signal can be acquired.

The average power of this reference signal formed in this way corresponds to the average power of the received undisturbed signal part. The average power of

the signal adjacent at the input of the decision unit corresponds to the aggregate power of received noise and signal part. The noise power is calculated therefrom with the assistance of the previously calculated, undisturbed signal part. The signal-to-noise ratio (SNR) as a criterion for the transmission quality of the transmission channel derives from the ratio of the average power of the undisturbed signal part to the average power of the noise part.

What such a method avoids is that the receiver must know a specific transmission sequence, as necessary given other, traditional methods. Moreover, the determination of the error rate ensues parallel to the evaluation of the transmitted symbols, i.e. online. A periodic introduction of a test sequence into the data stream to be transmitted is therefore no longer required for the continuous measurement of the transmission quality. In this way, a reduction of the net data rate of the transmission channel can be avoided.

In order to assure a high statistical dependability, a traditional method that employs a test sequence known to the transmitter and receiver must cover a great number of errors, usually several hundred. The traditional methods require very long measuring times in order to detect a corresponding plurality of errors for the very low bit error rates of, for example, 10^9 that are generally required. The inventive method, in contrast, is based on the interpretation of the measured signal-to-noise ratio during ongoing transmission. Since, however, only significantly shorter measuring times are required for the interpretation of the average powers when compared to the comparable interpretation of the symbol or, respectively, bit stream, the transmission quality can be determined far faster with the inventive method.

Dependent on the selected encoding and mapping method, there is always an unambiguous functional relationship between the signal-to-noise ratio 28 and a symbol error rate or, respectively, bit error rate. The signal-to-noise ratio thus qualifies the transmission properties of the channel and of the momentarily selected modulation or, respectively, demodulation method independently of the selected encoding or, respectively, mapping method. Via a measurement of the signal-to-noise ration 28 of a transmission channel 11, thus, the encoding or, respectively, the mapping method of the current modulation/demodulation method can be defined such

that a desired data throughput can be set for an error rate that can just be accepted. To this end, the identified signal-to-noise ratio 28 is supplied to a device 29 for determining a maximum transmission data rate 30 or, respectively, an encoding and mapping method. Dependent on the signal-to-noise ratio 28 preferably determined in decibels (dB) according to a known relationship, the device 29 defines an encoding and mapping method or, respectively, a maximum transmission data rate 30 for the current modulation and demodulation method that enables a maximum data throughput given the existing signal-to-noise ration 28. The maximally acceptable error rate 61 and of the modulation method 62 appear as parameters of the conversion characteristic of the device 29. Dependent on the measured transmission quality 28 of the transmission channel 11 and dependent on the current modulation/demodulation method 62 and dependent on a maximally allowed error rate in the transmission of the digital information 61, an encoding strategy (code 1, code 2, ...code 6) and mapping strategy (map point 1.... map point 6) can be selected in this way that, in view of the actual conditions, enables a maximum data throughput for the current modulation/demodulation method with a predetermined dependability.

The device 29 can be arranged both in the receiver 12 as well as in the transmitter 10. In any case, either the identified signal-to-noise ratio 28 or the identified maximum transmission data rate or, respectively, the selected encoding and mapping method 30 must be transmitted to the transmitter via a data connection 31.

The information about the encoding and mapping method with which a maximum transmission data rate 30 can be achieved for the current modulation/demodulation method is supplied to a control means 33 in the transmitter. On the basis of the maximally possible data transmission rate and the data transmission rate 32 respectively required for the transmission of digital information 13, this control device selects an actually employed data transmission rate 34 that is to be realized by an encoding, mapping and modulation strategy to be defined. This information data rate, on the one hand, and/or encoding, mapping and modulation method on the other hand is conducted both to the corresponding components of the channel encoder 14 of the transmitter 10 such as encoder 50, bit/symbol converter 15 and modulator 17, as well as via a data connection 35 to the corresponding

components of the channel decoder 20 of the receiver 12 such as demodulator 55, symbol/bit converter 24 and decoder 52.

The operation of the inventive apparatus upon system start of a transmission system is described below. The measuring of a transmission system is meaningfully implemented with the lowest possible transmission data rate (with reference to the respective modulation method) and with the maximally possible transmission power. In this way, a low symbol error rate is assured, this being a prerequisite for a high quality of a receiver-side signal-to-noise ratio measurement. In this case, the generally utilized adaptive methods for signal editing also exhibit the shortest transient times, and an optimally great system range is achieved with reference to a maximally allowable error rate. For defining the encoding and mapping method that allows a maximally possible transmission data rate for the transmission channel (and the momentarily utilized modulation method), only a single measurement is then required.

When, however, the desired data rate is to be enabled over different modulation methods, then a measuring procedure must be implemented for each possible modulation strategy.

The operation of the inventive transmission system during system operation is described below. Advantageously, the measurement of the transmission channel ensues online based on the transmitted data stream. A lowering of the net transmission data rate for realizing a transmission channel measurement ensuing outside of the payload data is therefore not required. The measuring of the signal-to-noise ratio of a transmission data rate that is actually employed suffices in order to be able to evaluate the transmission quality even with transmission data rates realized with the assistance of different encoding or, respectively, mapping rules. In advance, therefore, the system can also evaluate the transmission properties of other transmission data rates on the basis of the signal-to-noise ratio measurement implemented with a current data transmission rate. A repeated, iterative measurement for different transmission data rates is no longer required insofar as the modulation method is not modified.

As long as a transmission data rate is modified only on the basis of a new encoding rule or, respectively, mapping rule and not on the basis of a modified modulation method, the adaptive methods utilized in the demodulator also remain in the steady state. A change of the data rate is therefore possible interruption-free ("soft switching"). When, however, the adaptation of the data rate is realized via a change of the modulation strategy, then the system must be measured anew and a "soft switching" is not possible.

Fig. 2 describes an embodiment wherein the maximally possible transmission data rate is determined by receiver-side determination of the signal-to-noise ratio, and this maximally possible transmission data rate is communicated to the transmission side that in turn defines an actually employed transmission data rate on the basis of the requested and the maximally possible transmission data rate and forwards this to the corresponding components in the transmitter and receiver. In contrast thereto, Fig. 3 describes an exemplary embodiment that additionally implements a control of the output power of the transmitter. The adaptation of the transmission power to the channel and to the requested transmission method is referred to below as "power control". Insofar as Fig. 3 comprises the same devices as in Fig. 2, these are provided with the same reference characters. In this embodiment, the evaluation of the transmission quality 28 of the transmission channel 11 determined at the receiver side occurs at the transmitter side. To this end, the transmitter comprises a device 41 that, like the device 29 of Fig. 2, determines an encoding strategy or, respectively, a maximum transmission data rate of the transmission channel 11.

In addition to the transmission quality 28 determined by the receiver 12 and that is forwarded to the transmitter via the data connection 40, the device 41 also receives the data rate 32 required for the transmission of the digital information 13. An encoding or, respectively, mapping and modulation method having an actual transmission data rate 34 is selected on the basis of the respectively maximally permitted error rate for the transmission of the respective digital information 13. This selected transmission data rate 34, as in the embodiment described with reference to Fig. 2, is forwarded to the channel encoder 14 and to the channel decoder 20.

The signal values 44 generated by the modulator 14 are additionally forwarded in the transmitter 10 to a device 43 for regulating the transmission power. The signal 45 generated by the device 43 is subsequently transmitted via the transmission channel 11. The device 41 also determines the transmission power that is minimally required for the transmission. The identified transmission power is supplied to the transmission signal amplifier 43 via a transmission power signal 42.

Dependent on the difference between a measured transmission quality 46 of the transmission channel 11 and a transmission quality 47 that corresponds to the selected encoding or, respectively, mapping and modulation method (with a transmission data rate 34 and with a specific maximally allowed error rate), an adaptation of the transmission power of the transmission signal amplifier 43 is effected. I.e., when the identified transmission signal quality of the transmission channel 46 lies above the required transmission quality 47, the transmission power is correspondingly reduced. When the required transmission quality 47 lies above the transmission quality of the transmitter, then the transmission power must be raised.

In this second embodiment, thus, the difference from measured signal-to-noise ratio 46 and the signal-to-noise ratio 47 needed for the realization of a specific transmission data rate is a criterion for the boosting or, respectively, lowering of the momentary transmission signal power. When the transmission power needed for the realization of a specific transmission data rate cannot be produced by the transmission module, then the transmission system can at best realize the momentarily maximally possible transmission data rate as transmission data rate.

Such an inventive system for adapting a transmission system to the transmission channel employed is particularly suitable for employment of the "asymmetric digital subscriber line" technology. This, which is referred to as ADSL technology, like other XDSL technologies, makes traditional copper telephone lines compatible as high-speed servers for data-intensive applications. At the same time, the availability of the customary telephone voice services is preserved on the same line. Based on cabling that is already present, such technologies make data rates available that, for example exceed ISDN many times over. The limitations of the existing public information network are thus overcome, this having been hitherto

suitable only for the transmission of voice, text and graphics with low resolution. With such technologies, the traditional copper cable telephone networks becomes a high-performance system that is suitable for the transmission of multi-medium contents to all households.

By employing the traditional telephone lines, however, a high noise part is accepted, this becoming all the higher the greater the distance to be bridged becomes. The distance to be bridged in such technologies averages between 500 and 6 km. The noise part, however, increases not only with increasing length but also due to cross-talk from neighboring lines. With the assistance of the inventive, adaptive measurement and adaptation, the transmission system can be automatically adapted with such a method to the quality of the existing transmission line.